

Handoff Between a Wireless Local Area Network (WLAN) and a Wide Area Network (UMTS)

Traspaso entre una red inalámbrica de área local (WLAN) y una red de cobertura amplia (UMTS)

J. Sánchez-García

*Departamento de Electrónica y Telecomunicaciones, CICESE, México.
E-mail: jasan@cicese.mx*

Luis A. Villaseñor-González

*Departamento de Electrónica y Telecomunicaciones, CICESE, México.
E-mail: luisvi@cicese.mx*

Mario E. Vaquera-Flores

*Departamento de Electrónica y Telecomunicaciones, CICESE, México.
E-mail: vaquera@cicese.mx*

Raúl Aquino-Santos

*Facultad de Telemática, Universidad de Colima, México.
E-mail: aquinor@ucol.mx*

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Abstract

With the appearance of wireless data networks with variable coverage, bandwidth and handoff strategies, in addition to the growing need of mobile nodes to freely roam among these networks, the support of an interoperable handoff strategy for hybrid wireless data networks is a requirement that needs to be addressed. The current trend in wireless data networks is to offer multimedia access to mobile users by employing the wireless local area network (WLAN) standard IEEE802.11 while the user is located indoors; on the other hand, 3rd generation wireless networks (WAN) are being deployed to provide coverage while the user is located outdoors. As a result, the mobile node will require a handoff mechanism to allow the user to roam between WLAN and WAN environments; up to this date several strategies have been proposed (Sattari *et al.*, 2004 and HyoJin, 2007) in the literature, however, none of these have been standardized to date. To support this interoperability, the mobile node must be equipped with configurable wireless interfaces to support the handoff between the WLAN and the WAN networks. In this work a new algorithm is proposed to allow a mobile node to roam between a wireless local area network (IEEE802.11) and a WAN base station (UMTS), while employing IP mobility support. The algorithm is implemented in simulation, using the Network Simulator2.

Keywords: Handoff, WLAN, UMTS, MobileIP (MIP).

Resumen

Hoy en día existe una gran variedad de redes inalámbricas de datos que proporcionan coberturas variables, diferentes anchos de banda que implementan diferentes estrategias de traspaso; adicionalmente se presenta una gran demanda por parte de los usuarios móviles por utilizar libremente la cobertura que proporcionan este tipo de redes. Por lo anterior,

existe una necesidad de la implementación de mecanismos de traspaso que permitan la interoperabilidad en los traspasos que se presentan en redes inalámbricas híbridas. La tendencia actual, es la de proporcionar acceso para aplicaciones multimedia utilizando redes inalámbricas de área local (WLAN), utilizando el estándar IEEE 802.11 para interiores; por otro lado, se están instalando redes inalámbricas de 3ª generación para proporcionar cobertura en exteriores. Como resultado, los nodos móviles requieren un mecanismo de traspaso para permitir la comunicación en ambientes WLAN y WAN; a la fecha, se han propuesto diversas estrategias en la literatura (Sattari et al., 2004 y HyoJin, 2007); sin embargo, ninguna de éstas ha sido estandarizada. Para habilitar la interoperabilidad, el nodo móvil debe ser auto-configurable para permitir la movilidad entre las redes WLAN y WAN. En este trabajo se propone un algoritmo para permitir el traspaso de un nodo móvil dentro de una red inalámbrica de área local (IEEE 802.11) y una estación base WAN (UMTS), utilizando el soporte de movilidad IP. El algoritmo se implementó en simulación utilizando la herramienta Network Simulator 2.

Descriptores: Traspaso, redes inalámbricas de área local (WLAN), UMTS, IP Móvil (MIP).

I. Introduction

With the large deployment of WLAN access points (APs) in public places, high speed wireless data services are becoming increasingly popular, but they are not available everywhere. Similarly, cellular companies are migrating from second generation (2G) to 2.5 or 3G technologies, thus allowing them to offer higher data rate wide area network (WAN) connections that enable faster data transfers. Future wireless multimedia terminals will be able to connect to both WLANs and WANs, and switch between them without interrupting on going communication sessions.

It is highly advantageous to make use of WLAN networks, whenever they are available, and be able to switch to a wide area cellular network when the WLAN is no longer available. This is because WLANs (like IEEE 802.11) offer high data rates at the expense of a reduced coverage area (generally free), while WANs –like the General Packet Radio Service (GPRS) or Universal Mobile Telecommunications System (UMTS)– offer great geographic coverage, but with reduced data rates.

The handoff (HO) procedure is the mechanism by which a data connection in progress between a mobile terminal and a corresponding terminal is transferred from an access point (AP) to another one, or to a cellular network base station (BS). The HO from a WLAN AP to a UMTS base station should be made with very low priority, while the HO from a UMTS BS to an AP should be made whenever a WLAN is available, as a result of the increased bandwidth availability in WLANs (Pahlavan, et al., 2000); in addition, the utilization cost parameter must be considered too, as cellular operators

charge an additional fee to provide data services to their customers.

There are two HO types (Stemm et al., 1998): the horizontal HO that is defined like a HO between BSs (or APs) that are using the same wireless network technology, and the vertical HO which takes place between base stations that are using different wireless networking technologies; this work considers the vertical HO strategy, as well as, horizontal HOs between WLANs.

The vertical HO is divided in two categories: an ascendant vertical HO defined as a HO from a WLAN towards a wireless network with larger cell size whose coverage includes the WLAN, and a descendant vertical HO defined as a HO towards a wireless network with smaller cell size. To illustrate this procedure, figure 1 shows a person walking with a mobile terminal while connected to the Internet. As the terminal moves inside the hybrid network, several HOs must take place: starting at point a), the terminal passes from UMTS to a WLAN, this corresponds to a descendant vertical HO; point b) indicates the HO between two WLANs, called horizontal HO; point c) illustrates an ascendant vertical HO.

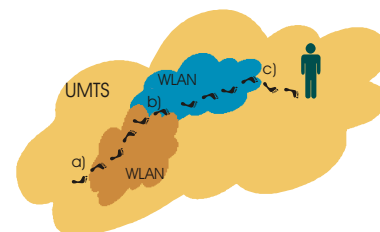


Figure 1. HO types: a) Descendant vertical HO, b) Horizontal HO, c) Ascendant vertical HO

A HO is triggered based on the availability of a network and the priority policy used to select a network. One of the parameters used to decide that a HO must take place corresponds to the Received Signal Strength Intensity (RSSI), but this is not enough to give priority to a network during the HO procedure; parameters like utilization cost and available bandwidth must also be considered. There are other methods that can be used to make the HO decision, like the one described in (Matusz *et al.*, 2003), where a HO decision is based on the throughput and a time hysteresis (in the order of seconds) is considered to avoid the ping-pong effect¹; however, the time they consider to wait for a handoff is relatively high and they do not specify the radio channel environment employed in their simulations.

In this work a *metric* is used to trigger the HO procedure; this *metric* is based on four parameters from each network: *cost*, *bandwidth*, *distance* and *RSSI* (each of these parameters is assigned a different weight). The vertical and horizontal HO mechanism is evaluated, while verifying that packet loss is minimized and the connection is maintained during the HO process.

The remainder of this paper is organized as follows. A review of recently proposed handoff procedures is presented in Section II. Section III describes possible ways to interconnect UMTS and WLAN. The mobility support in IPv4 is presented in Section IV. The proposed HO algorithm, inherent problems and the employed metrics are described in Section V. Section VI presents a description of the simulation model and the simulation scenarios employed. The simulation results are presented in Section VII. Finally, the conclusions of this work are presented in section VIII.

II. Related work

Sattari *et al.* (2004) propose a network architecture for a seamless handover between WLAN and UMTS, based on two already existing mobility protocols, Session Initiation Protocol (SIP) and Mobile IP. They define a Handover Entity, which is a set of functions located within the UMTS network, as the responsible for Handover Management. They propose three solutions: Mobile IP based, SIP based and a Hybrid based solution. Although they analyze the problems posed by each solution, they do not provide any simulation results.

Liu and Zhou (2005) propose an internetworking architecture between WLAN and UMTS, based on IPv6, Mobile IP and the 802.16 air interface (called Hybrid Coupling with Radio Access System). They propose two processes, one for vertical downward Handoff (a mobile node starts in a UMTS network and goes to a WLAN) and another for vertical upward Handoff. They compare their architecture with both a tight coupling and a loose coupling, showing that their proposal has a better performance (in terms of transmission and processing cost).

Sasikala *et al.* (2006) propose a Handoff technique from WLAN to UMTS, based on the loose coupling integration (independent architecture), aiming at the reduction of delay and packet loss when the mobile moves from a WLAN boundary to a UMTS network. The decision algorithm is based on the received signal strength, where the stations have to detect a weak received signal or failed frame transmission. They assume a hot spot WLAN is served by various Access Points (APs), where the boundary APs transmit a bit indicating that it is possible to exit the hot spot coverage. Their simulation results show a reduction in latency for the optimized algorithm, compared with the seamless technique.

Kim and Song (2007) propose a vertical Handoff scheme that uses Mobile IP, aiming at the reduction of the packet loss due to the ping pong effect. They assume that the WLAN is located as a hot spot inside the UMTS coverage area. The protocol is based on the received signal strength of both the WLAN AP and the UMTS base station; before making the Handoff decision, it verifies if the user is a pedestrian or if it is traveling on a motorized vehicle. To decrease the ping pong effect, the signal strength thresholds can be adjusted dynamically.

The proposal presented in this work differs from the previous approaches in the way the threshold variable (*metric*) is calculated; the proposed algorithm takes into account four parameters:

- Cost of the service
- Available bandwidth
- Distance to the AP (or BS)
- Signal strength

III. Interconnecting a WLAN and an UMTS Network

The transmit power is one of the main parameters that are worldwide regulated, and the transmitter power

¹ Several unnecessary HOs are triggered when the threshold is crossed several times during a short time.

varies among different regions. Many of the IEEE 802.11 wireless manufacturers have selected 100 mW as the transmit power level by default. In Europe 100 mW is the highest power level, while in North America the highest power level is 1000 mW (O'Hara *et al.*, 1999). The transmit power values used in base stations (BS node in UMTS), range from 30 dBm to 21 dBm according to the 3GPP Recommendation (3GPP TR 25.942 V3.1.0, 1999).

UMTS is a third generation wireless system (3G) developed in Europe and contemplated in IMT-2000 (*International Mobile Telecommunications 2000*), this is a 3G standard that includes several technologies, from which the dominants in the market are UMTS and cdma2000 (developed in the USA).

This work is based on UMTS TDD, as this was the model available in the simulation tool NS-2. One of the advantages of TDD is the fact that the transmission rates can be dynamically adjusted in the uplink and downlink, something that cannot be done in FDD mode because the links are symmetric. If the TDD downlink needs more slots and the uplink has available slots, the available slots may be transferred from the uplink to the downlink.

a) UMTS Network architecture

GPRS is the packet core network of UMTS. It includes two network nodes: the Serving GPRS Support Node

(SGSN) and the Gateway GPRS Support Node (GGSN). The SGSN monitors the user location and provides security and access control functions. The GGSN provides routing information of the connected users to the Packet Switched (PS) network and it provides interconnection with external PS networks.

The telecommunications technology trend is towards an IP world, for this purpose the 3GPP release 5 proposes an architecture as shown in figure 2. The foreign agent (FA) (or home agent, HA) functionality will be placed inside of the GGSN; the GGSN will send Agent Advertisements when it receives a Packet Data Protocol (PDP) request from a mobile equipment. Another proposal is that the SGSN and GGSN can be combined in a node called Internet GPRS Support Node (IGSN); the IGSN will act like a FA and will provide a tunnel to transfer packets from, and to, the user HA (3GPP TR 25.923 V3.0.0, 2000).

As can be appreciated from the 3GPP recommendations, the basis for the next generation network with IP convergence have been established; the 3GPP release 6 specifies the general procedures for the particular case of the HO between WLAN and UMTS. In the present work, the IGSN and Universal Terrestrial Radio Access (UTRA) were considered as a unique entity (figure 3).

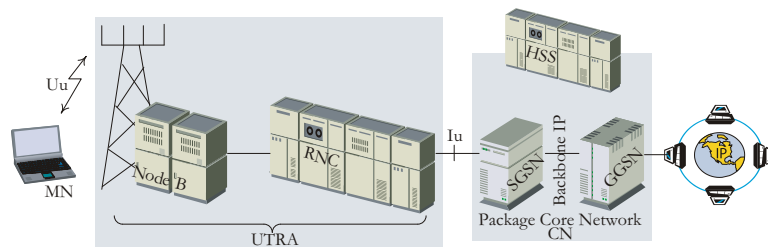


Figure 2. UMTS architecture release 5

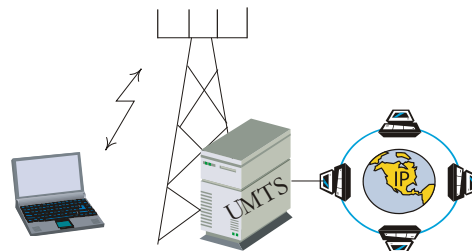


Figure 3. UTRAN and IGSN as a unit

b) UMTS and WLAN interconnection points

One of the main objectives in the WLAN and UMTS interconnection is to avoid, as much as possible, changes at the physical and link layers. This will insure that the current networks will keep working, without requiring the user to make changes at these lower layers; the approach proposed in this work is based on modifications at the network and upper layers.

There are two configuration scenarios for the interconnection of UMTS and WLANs; the first case is when the cellular operator is the administrator and owner of the WLAN, the second case is when the Wireless Internet Service Provider (WISP) is the owner. In the first scenario, the cellular operator has billing and authentication mechanisms that allow him the management and total control of the WLAN. In the case where the WLAN is operated by WISP, both operators will have their own billing and authentication mechanism (Salkintzis *et al.*, 2002).

Figure 4 shows the five possible options for the interconnection points between a UMTS and a WLAN (Prasad *et al.*, 2003). The interconnections (1) and (2) will always have interaction between the AP (via the Interworking Unit, IWU) and the UMTS Core Network (CN of PS UMTS); the interconnection is possible through the SGSN and GGSN respectively.

In the first interconnection point (known as *tight coupling*) the WLAN is connected as a UMTS cell, like any other Radio Access Network (RAN), through the Iu interface; where the Interworking Unit (IWU) is a

Radio Network Controller (RNC) emulator between the WLAN and SGSN. In the second interconnection point (known as *loose coupling*) the WLAN is connected as a routing area through the Gi interface; where the IWU is based in a SGSN emulator between the WLAN and GGSN. In both cases (1 and 2, in figure 4), UMTS will be the master network and WLAN the slave network, this means that UMTS manages the mobility and security issues (Prasad *et al.*, 2003). All the traffic will first reach the SGSN, or GGSN, before it arrives to its destination, even though the final destination is inside the WLAN, this is an inconvenient, because it may become a bottleneck in the UMTS network.

In the third interconnection method, the architecture is based in the Virtual Access Point (VAP) which reverses the function played by the components in the last two cases. Here, the WLAN is the master network and the UMTS is the slave. The mobility is managed according to the WLAN and the recent *draft Interaccess Point Protocol (IAPP)* which has been specified to standardize the communication between APs over the wired interface (Pahlavan *et al.*, 2000), but the architecture is not scalable because the VAP must always be associated with the *Extended Service Set (ESS)* of the WLAN. The transit technology (*when roaming*) that the WLAN sees is between different APs in the ESS and the VAP is considered as another WLAN AP. From the WLAN point of view, UMTS appears as a BSS or picocell associated with another AP (VAP, in this case). In the UMTS air interface, every packet will have double UDP/TCP and IP/PPP headers. Moreover, there will

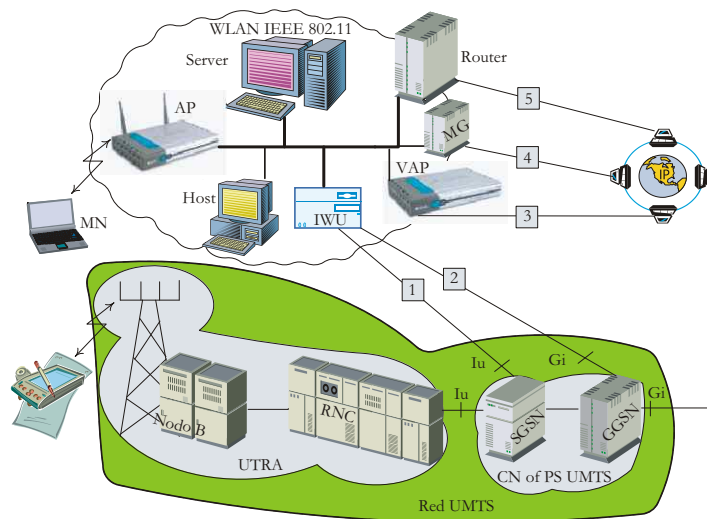


Figure 4. Interconnection architectures between WLAN IEEE 802.11 and UMTS

be a MAC 802.11 header in all the headers related with UMTS. This interconnection is considered inefficient, due to the excessive use of headers and it is not clear how will the VAP operate with the 802.11 AP (Prasad *et al.*, 2003).

The fourth interconnection method introduces a *mobility gateway* (MG) between the UMTS and WLAN networks. The MG is a proxy implemented in the UMTS or WLAN side. Its purpose is to manage the mobility and routing problems. But the real reduction of packet headers (*overhead*) by employing this architecture is not significant, due to the need for proprietary control protocols in addition to transit between different technologies.

Another proxy inconvenience is the poor performance due to increased latency in the client server communication trajectory and the fact that it is not easy to know the number of proxies needed to achieve an optimum performance.

The fifth interconnection method is based on mobile IP to handle the mobility management problems (known as *no coupling*). Here, UMTS and WLAN are peer to peer networks and the same problems exist as in the previous interconnection method (4); furthermore, the reference point that makes it possible to connect UMTS, via the GGSN, to the IP network operator or Internet is also the Gi interface (Salkintzis *et al.*, 2002). Since IP is in the core of actual and future wideband networks, this work employs this type of interconnection method (*i.e.* number 5).

IV. Mobility support in IPv4

The mobility support at the network layer has the advantage of being independent from the link layer. Mobile IP² implements the required functionality to prevent the disconnection of ongoing communication sessions during the handoff procedure of a mobile node (MN); the mobile node is always identified by its home address, independently of its current point of attachment to the Internet. While the mobile node is outside of its home IP sub-network, it can be associated to a care-of-address (COA); the COA indicates the current MN's localization. The following subsections explain with more detail the components and functionality of Mobile IPv4.

a) Mobile IPv4 Terminology

This section presents a description of the terminology employed in Mobile IPv4 (MIP)³.

Correspondent Node (CN). A node that communicates with a mobile node (MN). It can be mobile or stationary.

Encapsulate. Consist in adding a header to the original IP packet (*i.e.* packets are encapsulated).

Tunnel. A delivery path between two nodes where the packets payload are original packets.

Home Address. An IP address that is assigned for an extended period of time to a MN.

Care-of-address (COA). An address associated with a MN while it visits a foreign link.

Home Agent (HA). A router of the MN where it has registered its current COA.

Foreign Agent (FA). A router at the mobile node's visited network.

b) Mobile IP Functionality

The different tasks executed by the mobile nodes during the HO process are illustrated in figure 5.

The mobile agents advertise its presence via Agent Advertisement messages. An impatient MN may optionally solicit an Agent Advertisement message.

A MN receives the Agent Advertisements and determines whether it is located at its home network or at a foreign network.

Packets addressed to the mobile node arrive to the home network via standard IP routing (step 1).

When a MN moves away from its home network, it gets a COA at the foreign network, either by request or by listening to an Agent Advertisement; by contacting a Dynamic Host Configuration Protocol (DHCP); or by means of a Peer to Peer Protocol (PPP). While the MN is away from the home network, the MN registers every new COA with its HA.

While the MN is at a foreign network, the packets are intercepted by the HA, encapsulated and tunneled to the MN using the COA (step 2).

The encapsulated packets arrive to the FA, the external IP header is removed and the original packets are forwarded to the MN (step 3).

The data packets generated by the MN are routed by means of standard IP routing; this is the model employed in this work.

² IP and IPv4 are used interchangeably throughout the document.

³ The terms, and most of the functionality of the procedures that are presented in this section, are consistent with the terminology employed in the early paper by Perkins (2002).

In the reverse direction, packets sent by the MN are generally delivered to its destination, not necessarily passing through the home agent (step 4). This is known as triangulation.

c) MIP message flow during a HO procedure

The sequence of messages interchanged between the MN and the HA (via the Foreign Agent) are shown in figure 6.

d) Route optimization

To avoid the triangulation, it is possible to employ a route optimization mechanism; the idea is that the correspondent node (CN) will be able to directly send encapsulated packets to the mobile node by employing the MN's COA; this is achieved by means of a binding update message sent by the MN to the CN. The route optimization approach requires changes in the protocol stack of the CN. The route optimization mechanism is not employed in the actual MIP model used in this work.

e) Mobility detection at layer 3

The mobility agent (e.g. the HA or FA) periodically broadcasts Agent Advertisement messages, consequently the MN has the opportunity to verify if it is located at its home network or if it has moved to a foreign network. The HO mechanism is triggered by this type of message.

When the MN detects that it has moved to a different network (i.e. a foreign network) it gets a new COA by using the information provided in the Agent Advertisement messages sent by the mobile agents (e.g. the FA); once the MN has acquired a COA, it proceeds to register the new COA with the HA. It should be noted that several data packets may be lost during the HO

procedure, as the MN gets temporally disconnected during the period when the Agent Advertisement messages stop being received, to the time when the MN gets connected to another router; it is also possible that the MN receives messages from several agents and may get connected to the less appropriate. As a result, the MN can improve the HO procedure by employing additional information whenever this may be available at the MN, for example, by using the information provided from the physical layer (Perkins *et al.*, 1996; 2003).

This work considers that the MN has an Application Programmable Interface (API) to know its position and determine the distance to its current agent (by means of a Global Positioning System, GPS), and also to sense the power associated with the packets received from the advertising agents. It is also considered that the MN can receive packets from different base station with the same interface. Furthermore, it is assumed that Agent Advertisement messages provide the cost information, number of users and network type.

Each time a MN receives a mobility Agent Advertisement message, it verifies if the agent is already included in the *List of known mobility agents*, if it is not, it is added to the *List*. Then, the parameters (i.e. RSSI, Distance, Network Type, Network cost, Network users) are updated and stored. The consideration of these parameters (except Distance) in the decision for calculating a *metric* and choosing the preferred agent is one of the main contributions of this work. The Agent Advertisement messages are generated every second by the agents, and whenever the agents receive an Agent Request message. When the MN detects that it returns to its home network (by receiving an Agent Advertisement from its HA), the MN informs to its HA that it must stop intercepting packets addressed to it; consequently data packets sent to the MN by a CN will get routed directly to the MN within the home network. From this point on, the MN uses its home address as

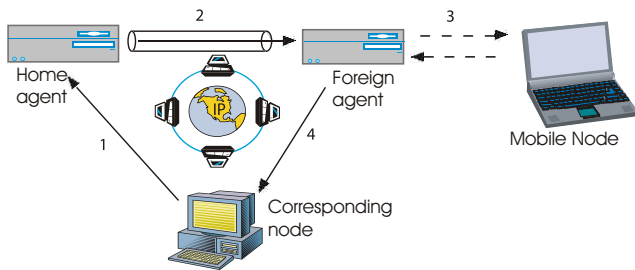


Figure 5. MIP Packet Flow Diagram

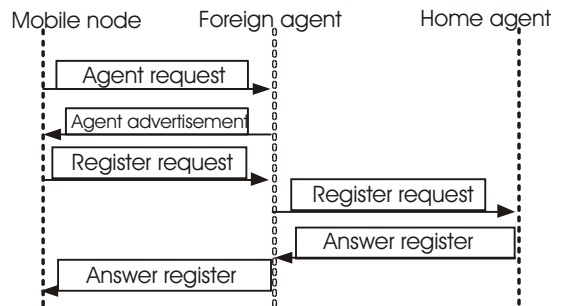


Figure 6. MIP packet flow during a HO procedure

the localization identifier instead of the COA. With the help of the MIP parameters described in this section, the MN can get a list of possible mobile agents to use, and with the aid of a HO algorithm determine which is more convenient to use. The next section explains some HO algorithms, including the HO algorithm proposed for this work.

V. Handoff algorithm

a) Handoff Procedure between WLAN and UMTS

The Handoff (HO) procedure employed by a MN to switch between WLAN and UMTS networks is illustrated in figure 7 (Prasad *et al.*, 2003).

There are four possible actions that may be taken by the MN as a result of the HO algorithm: While operating in the WLAN, the HO algorithm will select option A given that it receives a good signal strength from its current associated AP; option B indicates that the MN is beginning to receive a poor signal strength from the AP and should prepare to start a HO; option C is selected when a handoff to the UMTS network is required and there is not another WLAN AP to be selected; option D is selected to trigger a HO procedure to select a new WLAN AP.

The following scenario depicts a MN moving away from WLAN coverage and moving into UMTS coverage:

- 1) Initially, the MN receives a strong signal from the AP, and the MN is connected to the WLAN network.
- 2) As the MN moves away from the AP, the received signal strength becomes weaker. The MN is continually analyzing the received signals, looking for a better AP or BS. The HO algorithm uses the available

information to make a decision: to change, or not, to the UMTS network. The connection procedure is started to activate the UMTS wireless interface card.

- 3) The HO algorithm in the MN decides to disassociate from the WLAN and associate with the UMTS network.
- 4) The MN gets in touch with the foreign agent (FA) and obtains a COA.
- 5) The HA in the WLAN is informed about the new COA and begins the interception of datagrams addressed to the MN, it encapsulates them and sends them to his FA. The FA then deencapsulates the datagrams and delivers them to the MN.
- 6) If the MN moves into the WLAN coverage, it begins a reverse HO.

b) Handoff and the Ping-Pong effect

Handoff is the mechanism by which a data connection in progress between a mobile terminal and a corresponding terminal is transferred from a connection point to another: for example, as the MN moves away from a base station, the signal level gets weak and a handoff procedure must be executed to switch to another base station. The signal level degradation is a random process and a simple decision mechanism which is only based on the signal power measurement may result in the so called *ping-pong* effect (Pahlavan *et al.*, 2000). The ping-pong effect refers to several consecutive backward and forward HOs; this happens when the signal power is varying around the threshold value used within the HO algorithm to decide when to make a HO. This is an inconvenient for the user, due to the switching cost and the induced delay in each handoff.

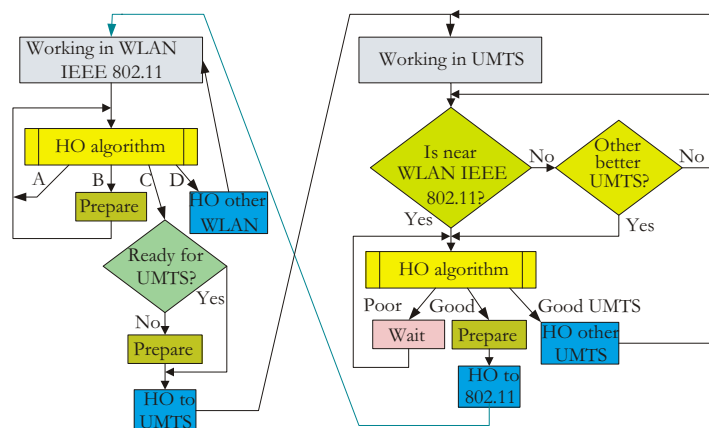


Figure 7. HO Procedure between WLAN and UMTS

c) Problems during the Handoff

The decision mechanism or *HO control* can be located in a network entity (like a cellular base station) or at the mobile node; these scenarios are called HO controlled by network and HO controlled by mobile, respectively. In GPRS, the information sent by the MN can be employed by the network entity to make the HO decision; this is called HO assisted by the mobile. In this work, the decision mechanism for HO is implemented at the MN.

This work employs the signal power, distance, network cost and available bandwidth parameters; furthermore, it uses a retain time counter and a hysteresis margin (*Hm*), which is not defined as a received signal power margin, but as a metric margin resulting from all the previous parameters. It also uses a metric threshold (*Um*).

d) Handoff algorithm

Almost all known algorithms are based in the received signal power (Pollini, 1996) and were designed for HO between the same types of networks (mostly for cellular networks). Other techniques have recently been proposed, like pattern recognition based on neuronal networks or diffuse logic systems, however these algorithms increase the computational cost in the mobile node; in addition, these techniques still employ the RSSI parameter.

This work follows a priority strategy for the HO between WLAN and UMTS, and different priorities, cost values and numbers of mobile nodes were pre-established during simulation⁴. The algorithm implemented in this model considers that UMTS and WLAN have different transmission signal strength levels, then it does not make sense to use only the RSSI parameter to decide among them (UMTS BSs generally transmit with a higher power strength than WLAN APs). If only this parameter is used, the MN will always be connected to UMTS, even if the MN was inside the WLAN coverage area. The use of a single RSSI parameter is appropriate for horizontal HO.

In the proposed HO algorithm, a new BS or AP will be chosen (called new agent, NA) if and only if the following two conditions are met:

during a predetermined retention time (*Dwell-timer*) the new agent metric (*metric_NA*) minus an hysteresis margin is greater than the metric of the actual or older agent (*metric_VA*) (Eq. 2) and, the actual agent metric (*metric_VA*) is smaller than a predefined threshold (*Um*) value.

The agent metrics are calculated by taking into account several parameters, according to the following equation:

$$\begin{aligned} \text{metric} = & \text{weight_Cost}(1-\text{Cost}) \\ & + \text{weight_BandWidth}(BW_user) \\ & + \text{weight_Distance}(1-\text{Distance}) \\ & + \text{weight_RSSI}(RSSI) \end{aligned} \quad (1)$$

A new agent (NA) is chosen if at the end of *Dwell-timer* the following inequality holds true:

$$\text{metric_NA} - Hm > \text{metric_VA} < Um \quad (2)$$

*Um*⁵ is a threshold which is used to determine if the *metric_VA* is poor.

In equation , the variables denoted with the prefix “weight” have a value between 0 and 1, and added are equal to one. *Cost* is a value that represents the network charge (from 0 to 1). *BW_user* is the bandwidth that corresponds to the MN, which is calculated by dividing the total bandwidth used in the network by the number of MNs in that network. The variable *Distance* is the normalized distance that exists between the MN and the BS or AP. Finally the *RSSI* variable is the strength indicator from the received signal. To avoid choosing an agent which is received with very low power, a *RSSI_Threshold* is defined, such that the agent metric (i.e. *metric_NA* or *metric_VA*) is set to zero when its strength is below the *threshold*:

$$\text{if } RSSI < RSSI_Threshold \text{ then } \text{metric} = 0 \quad (3)$$

During a HO procedure the MN follows the next sequence of steps:

- 1) The MN *Link-Timer* is restarted every 0.5 seconds.
- 2) The *HO-trigger* function verifies if *Dwell-Timer* is less or equal to zero. If so, *Monitor-timer* is reset

⁴ The WLAN AP can report how many users are currently connected to it, in order for the MN to roughly estimate the available bandwidth; the same criteria can be used in the UMTS.

⁵ During simulations it was observed that *Um* delayed the HO without any benefit; then a value of 100 was used to speed up the HO procedure.

and returns a *HO-Trigger Authorization*. Otherwise, the function returns a *HO-Trigger Deny*.

- 3) If the MN is not associated to any network and the *HO-Trigger* is authorized, the MN sends a *HO-Request* to both, UMTS and WLAN networks.
- 4) The base station receives the Agent Request and answers with an Agent Advertisement.
- 5) If the third step condition is not fulfilled, the *Link-Timer* is restarted.

VI. Implementation of the simulation model

The UMTS TDD extension for the Network Simulator (NS-2) was developed at the University of Roma (Vacirca *et al.*, 2003) using the ns-2.1b9a distribution, which had to be ported to the ns-2.1b7a version of NS-2, as we had an available work in progress from several universities regarding the HO between UMTS and WLAN from which we started our work. The implementation of the simulation model was done as part of a thesis developed at CICESE (Vaquera, 2004).

The UMTS-TDD extension manual for NS-2 (Todini *et al.*, 2003) (preliminary version), provides a description and enough instructions to understand its implementation and how to develop simulations.

a) Autoconfigurable mobile node

To simulate a mobile node, a terminal model with a common layer 3 and two different lower layers (one for UMTS and another for 802.11) was considered. The module that performs the interface between the common layer 3 protocol and the two different lower protocol stacks (MAC and PHY sublayers) is called *RAMON* (Reconfigurable Access Module for Mobile Computing Applications).

RAMON is a project developed at several Italian universities, among them the Palermo University; it consists of several interfaces added to the original ns-2 MN model, as can be seen in figure 8. The primitives sent between layer 3 and layers 2 are handled transparently by means of adaptation layers related to UMTS and 802.11, respectively. The *RAMON* node model makes use of two submodules: the Radio Resources Control (RRC) and the Mobility Management (MM), as illustrated in figure 8. To calculate the attenuation of the radio signal, the model employs the *Friss free space* propagation model ($1/r^2$ where r is the distance) for short distances and an approximation to Two Ray Ground ($1/r^4$) in long distances. The approximation assumes that flat earth reflection occurs.

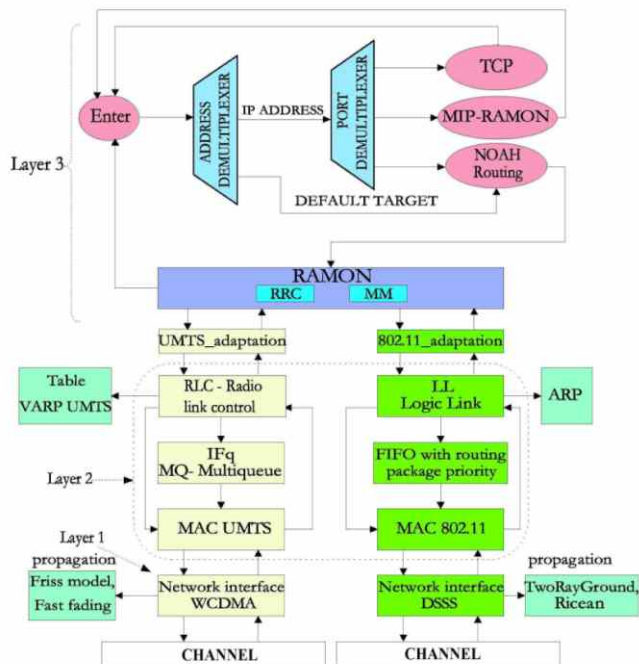


Figure 8. Reconfigurable node with two interfaces in NS-2

The routing protocol employed for this infrastructure network is NOAH (no Ad-Hoc) (Widmer, 2004). The cost and number of users can be established for every network; the bandwidth of every network is divided between the number of users of that specific network. The node is autoconfigurable and before simulation the user can define several parameters like *weight_Cost*, *weight_Distance*, *weight_BandWidth*, *weight_RSSI*, the number of verifications (*num_checks*) before executing a HO procedure to avoid the ping-pong effect, and the *RSSI_Threshold* that will be used to trigger the HOs. The *RSSI* and *RSSI_Threshold* parameters were included into the RAMON model and are part of the contributions of this work.

b) Network scenario employed for HO

The simulation scenario considers a topology composed by one UMTS and two WLAN networks; the home agent (HA) is located at the UMTS network BS (the NS-2 UMTS module only supports the home network to be located at the UMTS network) and the foreign agents are the routers from the WLANs, as it is illustrated in figure 9. The simulation begins with the MN connected to the UMTS network and moving to a WLAN network with a constant speed of 3 km/h (0.8333 m/s). The simulation time is 70 sec. and at $t = 0.1$ sec. the MN (node 4 in the animator of NS-2, figure 10) begins to move towards the first WLAN access point (AP0 or node 5). The following paragraphs describe the movements made by the MN, which are illustrated in figure 9:

- The MN performs a descendant vertical HO crossing from UMTS to WLAN.

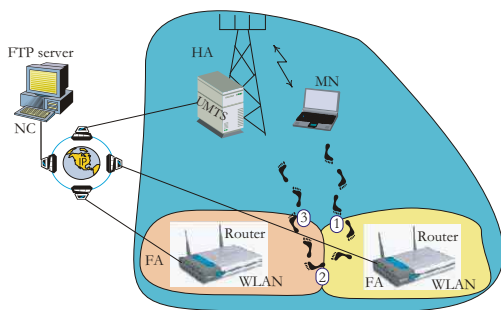


Figure 9. Mobility scenario with one UMTS and two WLANs

- At $t = 30.0$, the MN changes its direction and moves towards the other WLAN (AP1), thus executing a horizontal HO. The second WLAN is denoted by node 6 in figure 10.
- At $t = 50.0$, the MN changes again direction towards the UMTS to perform an ascendant vertical HO passing from WLAN to UMTS. The UMTS BS is represented by node 3 in .

During simulation, the MN opens a TCP connection by means of an FTP application; packets are sent from the FTP server (i.e. the correspondent node denoted as node 1 in figure 10) towards the MN. Data transfer begins at $t = 0.2$ sec. There are two intermediate nodes representing the Internet cloud, as illustrated in figure 10; these two routers are denoted with the node numbers 0 and 2. All the nodes have an associated hierarchical address.

The Agent Advertisement messages are broadcasted every second, and the reset time of the monitoring, link and connection timers is 0.5 sec.

VII. Results and numeric analysis

The measured parameters in the simulation were: point to point delay, number of packets lost and HO delay. In addition, this section presents a comparative analysis between the results obtained for vertical (ascending and descending) and horizontal HOs.

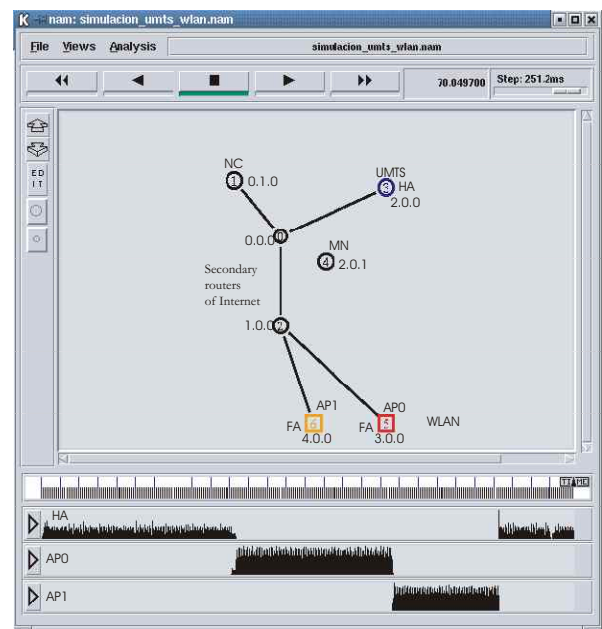


Figure 10. NAM visualization screen

a) Simulation parameters

Figure 10 illustrates the Network Animator (NAM) visualization of the network topology implemented for simulation in NS-2. The lower section of figure 10 shows the generated traffic between the agents and the mobile node (MN).

Table 1 shows the parameters employed for simulations; these values were obtained from (Vaquera, 2004) and represent a typical example, where the most important parameter is considered to be the associated network cost defined by the *weight_Cost* parameter.

Table 1. Simulation Parameters

Parameter	Value
<i>num_checks</i>	1
<i>weight_Cost</i>	0.7
<i>weight_Distance</i>	0.1
<i>weight_Bandwidth</i>	0.1
<i>weight_RSSI</i>	0.1
<i>RSSI_Threshold</i>	-79.4 dBm

b) Performance results

In this section we present the performance results for the point to point delay and the HOs delay. During normal operation conditions there were no packets

lost⁶ in any of the simulated HO scenarios, except when the operation was under abnormal conditions; for example a person running at a speed of 20 m/s (72 km/h), and carrying his mobile terminal. Performance results for this last scenario are not presented in this work.

1. Handoff from UMTS to WLAN

The HO delay can be visualized in table 2; the delay to complete the HO is measured from the time the HO is triggered, until the time the MN finds itself connected to the new network.

Figure 11 shows the results obtained for the delay of the packets from the CN to MN (end to end); this figure illustrates the delay before and after the HO is made between UMTS and the first WLAN. It is observed that the delay is larger when the MN is connected to the UMTS, than when it is connected to the WLAN.

The received signal strength from the UMTS BS and the WLAN AP0 are shown in figure 12 and figure 13, respectively. Figure 14 shows the results of the RSSI that the MN measures from the UMTS BS; this information is presented as a function of the distance between the BS and the MN. An overlap is observed in (i.e. between distances 64 and 70 meters), this is due to the fact that the MN reaches a maximum distance at around 69 mts. and then it begins to come back closer to the UMTS BS.

⁶ Packets transmitted from the BS, or the AP, to the MN.

Table 2. HO Delay from UMTS to WLAN

Event Time	State	Event
23.720026	Connect	HO Trigger from distance 57.156366
23.720026	HO	HO Start from BS 2.0.0
23.768811	HO	Sent MIPT_REG for: 2.0.0
23.768811	HO	Sent MIPT_REG for: 3.0.0
23.784171	HO	Received REG_REPLY
23.784171	HO	HO Execution: from 2.0.0 to 3.0.0
23.784171	HO	Detach from 2.0.0
23.784171	IDLE	Attach to 3.0.0, MH has new coa 3.0.0
23.801215	Connect	Sent MIPT_REG for: 3.0.0
Total	---	0.081189 HO total time

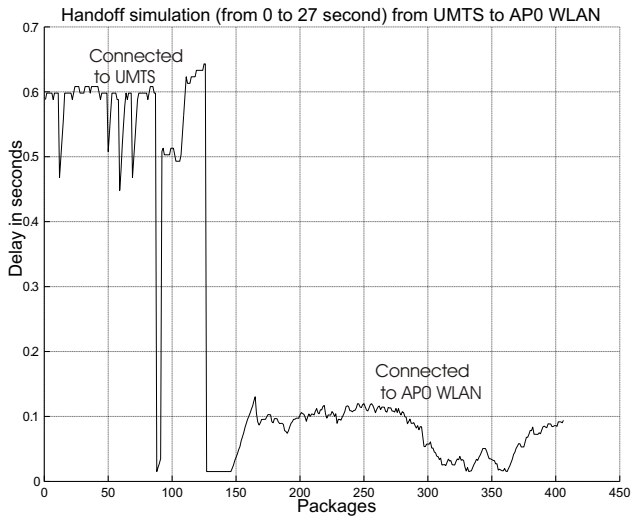


Figure 11. Simulation results of the packet delay metric

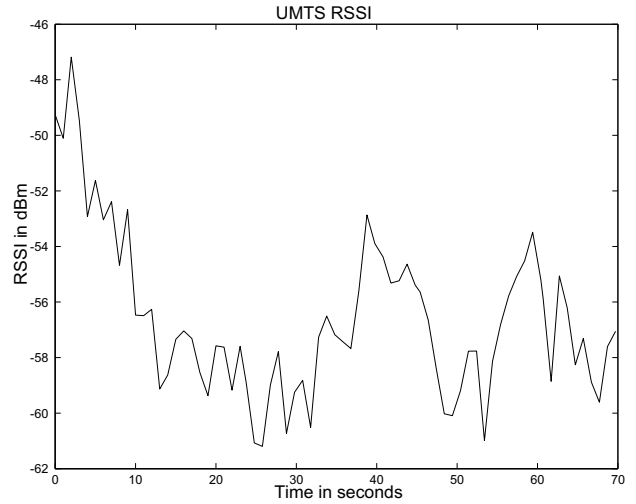


Figure 12. RSSI of the UMTS BS

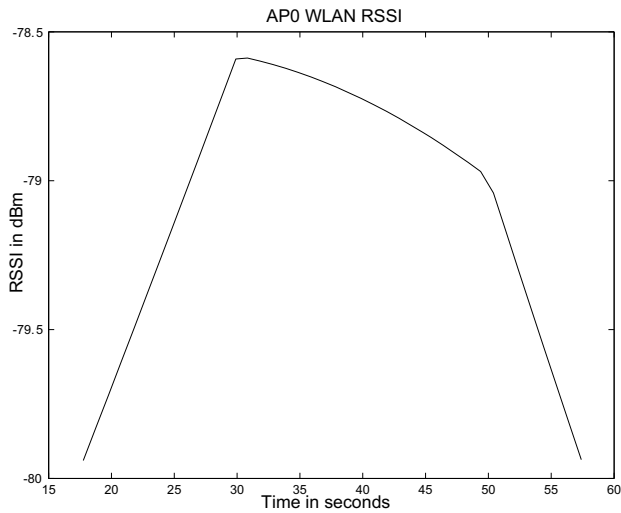


Figure 13. RSSI of the WLAN AP0

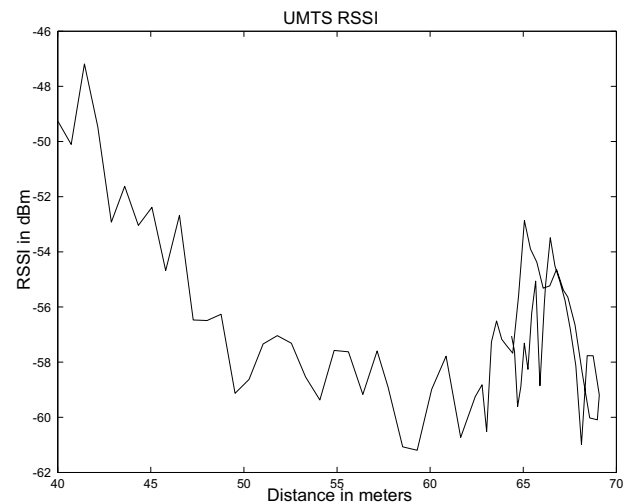


Figure 14. RSSI of UMTS BS as a function of distance

2. Handoff between WLANs

The end to end delay of data packets sent from the CN to MN is shown in figure 15; the delay measurements are taken between $t_1 = 43.0$ and $t_2 = 49.0$ to include the horizontal HO procedure between AP0 and AP1. Table 3 shows the HO delay measured from the time the HO is triggered to the time when the MN is connected to the new network.

3. Handoff from WLAN to UMTS

The packet end to end delay (i.e. CN to MN) is shown in figure 17; these results were obtained some seconds before and after the HO from the second AP WLAN to UMTS. Table 4 shows the HO delay measured from the time the HO is triggered to the time when the MN is connected to the UMTS again.

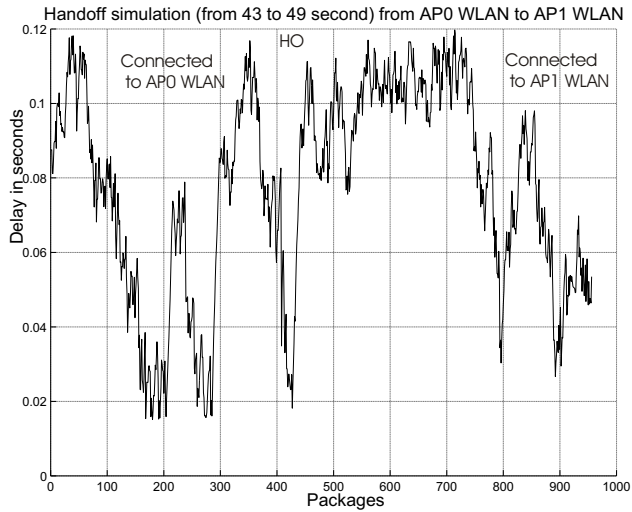


Figure 15. Packet delay during the horizontal HO

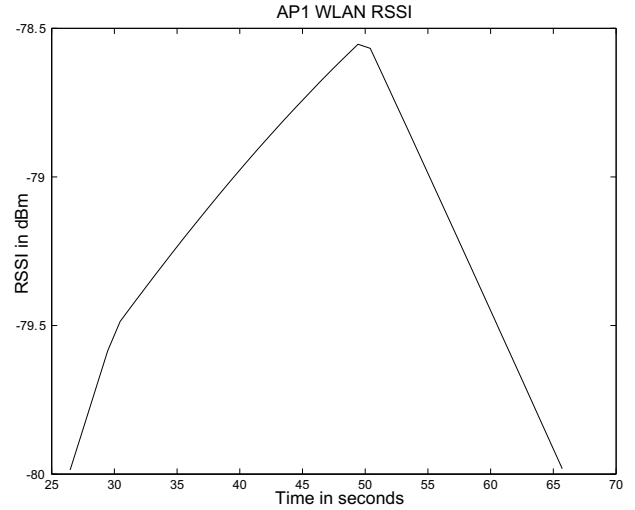


Figure 16. RSSI of the AP1 WLAN

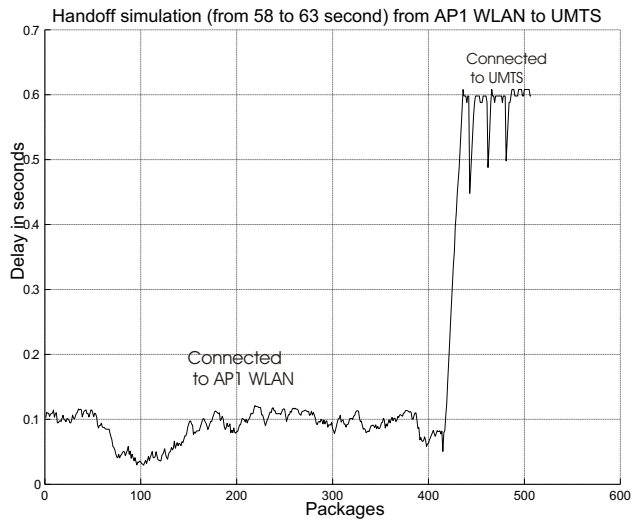


Figure 17. Packet delay during ascendant vertical HO

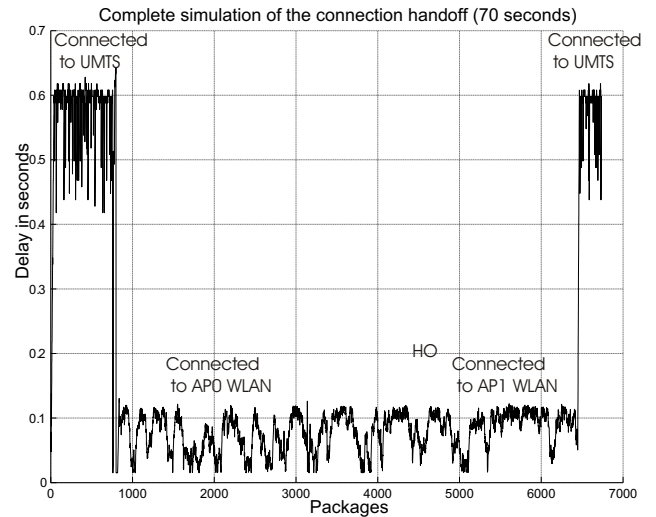


Figure 18. Packet delay during simulation

4. Comparison between HOs

This section presents a comparison and analysis of the HO results derived by simulation; performance results are evaluated in terms of the point-to-point packet delay and HO delay.

Point-to-point packet delay

Figure 18 shows the delay of the packets (packet size was set to 1000 bytes) during the entire simulation.

The packets that went through the UMTS BS, when the MN was connected to that agent, are the most delayed. Since the WLAN's effective bit rate is larger than that of UMTS, it was found in the simulations that the packets suffer less delay when transmitted through the WLAN APs.

HO delay

Table 5 shows the measured delays during the HOs. It can be observed that the HO delay is larger between WLANs, where it was expected to be smaller, but this delay is random and is due to the *Dwell* and *Link* timers employed. This can be confirmed by observing the delay between “HO Start” and the first “Sent MIPT_REG” in table 2, table 3 and table 4, which are equivalent to 0.048785, 0.164219 and 0.009106 sec. respectively. The use of timers can be considered as a problem that reduces the efficiency, but is necessary to avoid the “ping-pong” effect.

Table 6 shows the HO delay at the transport layer (TCP). It is observed that the MN can receive packets from two connections at the same time; this happens when the MN (during a HO) is beginning to receive

packets from the new agent while there are pending packets (from the old agent) still on the air or cable. The “Detach” operation denoted in table 2, table 3 and table 4, does not imply disabling the interface, and the MN can still receive packets from the previous BS or AP.

Figure 19 presents the graphics obtained for the measured RSSI at the MN from the UMTS BS, and from the access points located in both WLANs, during the entire simulation. The solid line represents the UMTS signal that MN receives and is present at all times, the cross and asterisk lines represent the signals of AP0 and AP1 respectively. It can be observed that the MN receives them with a RSSI greater than -80 dBm, good enough to connect with the network from which it receives the stronger signal. The vertical lines indicate the time at which the HOs are triggered.

Table 3. HO Delay from WLAN to WLAN

Event Time	State	Event
45.284171	Connect	HO Trigger from distance 100.184815
45.284171	HO	HO Start from BS 3.0.0
45.448390	HO	Sent MIPT_REG for: 3.0.0
45.448390	HO	Sent MIPT_REG for: 4.0.0
45.574707	HO	Received REG_REPLY
45.590894	HO	Received REG_REPLY
45.590894	HO	HO Execution: from 3.0.0 to 4.0.0
45.590894	HO	Detach from 3.0.0
45.590894	IDLE	Attach to 3.0.0,MH has new coa 4.0.0
45.600000	Connect	Start Monitor
Total	---	0.315829 HO total time

Table 4. HO delay from WLAN to UMTS

Event Time	State	Event
60.590894	Connect	HO Trigger from distance 103.447349
60.590894	HO	HO Start from BS 4.0.0
60.600000	HO	Start Monitor
60.600000	HO	Start HO Detection:ho_timer=0
60.600000	HO	Sent MIPT_REG for: 2.0.0
60.640328	HO	Received REG_REPLY
60.640328	HO	HO Execution:from 4.0.0 to 2.0.0
60.640328	HO	Detach from 4.0.0
60.640328	IDLE	Attach to 2.0.0,MH has new coa 2.0.0
60.698995	Connect	Sent MIPT_REG for: 2.0.0
Total	---	0.108101 HO total time

Table 5. HOs Delay

HO Delay (sec.)	HO Event
0.081189	UMTS to WLAN
0.315829	WLAN to WLAN
0.108101	WLAN to UMTS

Table 6. HO delay at the transport layer (TCP)

HO Direction	Time
From UMTS to WLAN	
Last package received in MN by part of BS	25.4102 sec
First package received in the MN by part of AP0	24.8473 sec
Absolute difference	0.5629 sec
From WLAN to WLAN	
Last package received in MN by part of AP0	46.1370 sec
First package received in the MN by part of AP1	45.9917 sec
Absolute difference	0.1454 sec
From WLAN to UMTS	
Last package received in MN by part of AP1	60.1731 sec
First package received in the MN by part of BS	60.1703 sec
Absolute difference	0.0028 sec

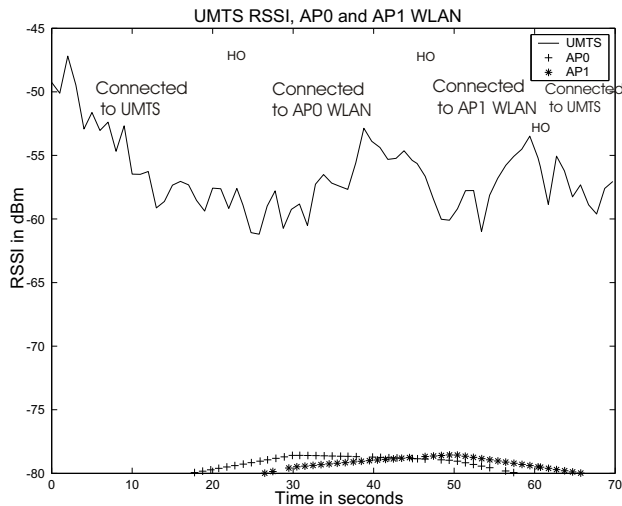


Figure 19. UMTS BS and APs RSSI during simulation

VIII. Conclusions

Different alternatives for handoff between WLAN and UMTS were analyzed. In this work we implemented a HO algorithm while trying to reduce complexity and provide the best advantages (no coupling MIP based) of other previously reported HO approaches. The vertical and horizontal HOs are performed without losing any ongoing TCP connections and without losing packets.

A novel algorithm was proposed, implemented and evaluated to support horizontal and vertical handoffs between UMTS and WLAN networks; the HO algorithm relies on several metrics, including the RSSI. Previous works implement various algorithms, some of them even with high computational cost, as those that make use of neural networks, but still they rely on the RSSI metric.

It was concluded that the interconnection architecture between UMTS and WLAN by means of MIP represent a viable alternative to enable roaming between networks. The HO delay (with TCP) doesn't significantly affect the file transfer services, data and email, but it may affect real time applications, since it sometimes exceed the maximum allowed delay considered acceptable for voice and video applications (500 msec.). However, if the HOs do not occur frequently, the introduced HO delay may be considered not so annoying for voice or video applications.

The performance results in this work considered a TDD based UMTS network; however, recent extensions to the NS-2 UMTS model have implemented the

FDD model, as a result, future work will consider the implementation of an FDD based UMTS network.

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About the authors

Jaime Sánchez-García. Received the engineering degree in electronics and communications from IPN-ESIME, Mexico (1976); a M.Sc. in electronics and telecommunications from CICESE Mexico (1979) and the D.Sc. in electrical engineering (major in communications) from The George Washington University (2001). Since 1979, he holds a research and faculty position at CICESE's electronics and telecommunications department. He won the 1st place in III Ericsson Yearly Award (1988) in México. His publications include several IEEE articles and international conferences. Current research interests include wireless and sensor networks, software radio, radio channel modeling and multicarrier CDMA. He is an IEEE and a IEICE member.

Luis A. Villaseñor-González. Received an engineering degree in electronics from UABC, Mexico (1993); M.Sc. in electronics and telecommunications from CICESE, Mexico (1997); and PhD in electrical engineering from the University of Ottawa in 2002. He is currently a research professor at the CICESE research center. He collaborated as a network research engineer at the Communications Research Centre in Ottawa, Canada. At CRC he was involved in a variety of research activities in network technologies for the Government of Canada between 1999 and 2003. His current research interests include Mobile Ad-hoc networks, wireless communications networks, QoS protocol architectures, performance analysis and evaluation of Internet technologies and computer networks. He is currently a member of the IEEE.

Mario E. Vaquera-Flores. Received a M.Sc. in electronics and telecommunications from CICESE, Mexico (2004).

Raúl Aquino-Santos. Received the electrical engineering degree from the University of Colima (1988); M.Sc. in electronics and telecommunications from CICESE, Mexico (1990); PhD degree from The University of Sheffield, England (2004). From 1990 to 1996 he was in charge of The Telecommunications and Networks Department of the University of Colima, and from 1996 to 2000 he was the director of the Faculty of Telematics. He has imparted several national and international courses and conferences related to information technologies, telecommunications, networks and multimedia. He has national and international publications, and has supervised several thesis and projects in undergraduate and postgraduate programs since 1990.